(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 898 174 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
24.02.1999 Bulletin 1999/08

(51) Int. Cl.[6]: G01S 7/285, H01Q 3/24, H01Q 3/26, G01S 13/44

(21) Application number: 98103806.0

(22) Date of filing: 04.03.1998

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 18.08.1997 JP 221372/97

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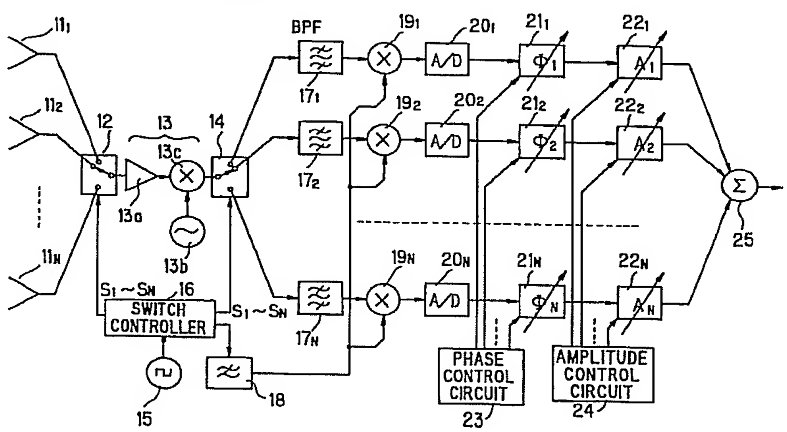
(54) Radar apparatus

(57) An array antenna radar apparatus has a single front end shared by a plurality of antennas, a first switch for cyclically connecting the antennas to the front end at a prescribed switching frequency, and a second switch for cyclically connecting the output of the front end to frequency converters corresponding to the antennas. The frequency converters frequency-convert intermediate-frequency signals of the respective antennas output by the front end to baseband signals at the switching frequency. Phase shifters and amplitude adjusting units apply a phase shift or amplitude adjustment to the outputs of the frequency converters and combine the resulting signals, thereby making it possible to detect a target in a desired direction.

FIG.1



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are disposed at the outputs of the RF amplifiers 3a ~ 3n, (2) IF filters 101a ~ 101n are provided for extracting intermediate-frequency components from the output signals of the frequency converters 6a ~ 6n, respectively, (3) A/D converters 102a ~ 102n are provided for converting the analog outputs of the IF filters to digital data, and (4) control of phase shift and amplitude is executed by digital processing using a DSP (Digital Signal Processor) or the like.

[0010] The DBFN-type receiver apparatus is so adapted that reception signals from the antennas 1a ~ 1n are amplified by the RF amplifiers 3a ~ 3n, respectively, and then subjected to a frequency conversion by the frequency converters 6a ~ 6n, respectively. The IF filters 101a ~ 101n extract intermediate-frequency components from the outputs of the frequency converters 6a ~ 6n, respectively, and the A/D converters 102a ~ 102n convert the IF signals to digital data. The DSP controls the amount of phase shift and adjusts amplitude by digital processing, and the adder 10 combines the resulting signals in terms of their vectors. As a result of this operation, a desired beam pattern is formed and the direction of detection is controlled. This is a principle exactly the same as that of the active phased array configuration described above.

[0011] Further, as shown in Fig. 26, an arrangement may be adopted in which a plurality of phase-shift/amplitude-adjustment means 103a ~ 103m are provided, digital data output by the A/D converters 102a ~ 102n is input to each of the phase-shift/amplitude-adjustment means 103a ~ 103m, these input signals are subjected to separate phase shifts and amplitude adjustments by each of the phase-shift/amplitude-adjustment means 103a ~ 103m and each of the phase-shift/amplitude-adjustment means 103a ~ 103m combines the resulting signals and outputs the result. Adopting this arrangement makes it possible to form a plurality of emission patterns simultaneously so that signals from a plurality of directions can be distinguished among and obtained simultaneously. In the arrangement of Fig. 26, the active phased array technique and the beam switching technique can be realized at the same time. It should be noted that the reason for using digital circuitry is ease of design and manufacture.

[0012] A scheme in addition to the active phased array system that can be used to detect the direction of a target is the monopulse technique. Unlike the active phased array configuration, the monopulse scheme receives reflected power from a target by two antennas and compares the phases or amplitudes of the reflected power received by the two antennas to thereby estimate and detect the direction of the target (the signal arrival direction).

[0013] Fig. 27 is a diagram showing the construction of the receiver in a monopulse radar apparatus. The receiver includes antennas 110a, 110b, low-noise RF amplifiers 111a, 111b, local oscillators 112a, 112b, frequency converters 113a, 113b, IF filters 114a, 114b, A/D converters 115a, 115b for converting IF signals to digital data, a phase comparator circuit 116 for comparing the phases of signals received by the two antennas, an amplitude comparator circuit 117 for comparing the amplitudes of the signals received by the two antennas, and an arrival direction estimating circuit 118 for estimating the direction of a target (the signal arrival direction) based upon a phase difference or amplitude distance.

[0014] Though the two receiving antennas 110a, 110b point in substantially the same direction, the positions at which they are placed differ slightly. Consequently, the radiation beam patterns overlap with a slight offset between them. If the target is at equal distances from both antennas, the phases of the received signals that arrive at the two antennas 110a, 110b will be equal. If the target is closer to one antenna than the other, however, the signal arrival direction (the target direction) can be estimated from the phase difference between the two signals arriving at the respective antennas and the spacing between the antennas. The monopulse radar apparatus estimates the direction of the target in accordance with this principle.

[0015] The beam switching arrangement in which the antennas are switched among necessitates a plurality of independent antennas. It is required that the individual beam widths be comparatively small. In addition, depending upon the radar application, it is often required that the beam widths be uniformalized as well as the antenna gains. As a consequence, a plurality of antennas having comparatively large areas are required and, hence, the area occupied by the antennas is several times larger than that of a radar apparatus devoid of beam control or of a radar apparatus of the active phased array type. The cost of manufacturing the antenna components is high as well. Further, according to the beam switching system, control of detection direction is performed in discrete fashion by switching among the plurality of antennas having different directivities. As a result, the angular resolution of the target is limited by the beam widths of the individual antennas and the number of antennas.

[0016] With the active phased array and DBFN systems, a plurality of antenna radiation patterns are combined to obtain a single radiation pattern having the desired directivity. This means that it is unnecessary to enlarge the size of the antennas, as is required in the beam switching system. Further, by continuously varying the amount of phase shift and the amount of amplitude adjustment, continuous control of detection direction becomes possible, as set forth above. This makes it possible to increase angular resolution. However, the active phased array and DBFN systems require the individual RF receiver circuits for the plurality of antennas. This increases the size, complexity and manufacturing cost of the apparatus. Further, a manufacturing variance in the amplitude and phase characteristics specific to the circuitry and a manufacturing

and reception, and a third switch for alternately switching an antenna, which has been selected by a first switch, to a transmitter circuit and a front end.

[0025] Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026]

Fig. 1 is a diagram showing the construction of a radar apparatus according to a first embodiment of the present invention;
Fig. 2 is a time chart illustrating antenna switching timing;
Figs. 3A ~ 3C are spectrum diagrams useful in describing the operations of various components;
Fig. 4 is a diagram showing a first modification of amplitude control according to the first embodiment;
Fig. 5 is a diagram useful in describing amplitude weightings of corresponding antennas;
Fig. 6 is a diagram useful in describing switch-on times of amplitude control;
Fig. 7 is a diagram showing a radar apparatus according to a second modification of the present invention;
Fig. 8 is a diagram showing a radar apparatus according to a third modification of the present invention;
Fig. 9 is a diagram showing a radar apparatus according to a fourth modification of the present invention;
Fig. 10 is a diagram showing the construction of a radar apparatus according to a second embodiment of the present invention;
Fig. 11 is a time chart of antenna selection signals and A/D converter sampling signals;
Fig. 12 is a diagram showing a radar apparatus according to a first modification of the second embodiment;
Fig. 13 is a diagram showing a radar apparatus according to a second modification of the second embodiment;
Fig. 14 is a time chart for describing the operation of the second modification;
Fig. 15 is a diagram showing the construction of a monopulse radar apparatus according to a third embodiment of the present invention;
Fig. 16 is a diagram showing a radar apparatus which is a modification of the third embodiment;
Fig. 17 is a diagram showing the construction of a radar apparatus according to a fourth embodiment for a case where all antennas are used for both transmission and reception;
Fig. 18 is a time chart of antenna selection transmission/reception changeover according to the fourth embodiment;
Fig. 19 is a diagram showing the construction of a radar apparatus according to a fifth embodiment for a case where one antenna is used for both transmission and reception;
Fig. 20 is a time chart of antenna selection transmission/reception changeover according to the fifth embodiment;
Fig. 21 is a diagram showing the construction of a radar apparatus according to a sixth embodiment for a case where all antennas are used for both transmission and reception;
Fig. 22 is a time chart of antenna selection transmission/reception changeover according to the sixth embodiment;
Fig. 23 is a diagram showing the construction of a monopulse radar apparatus according to a seventh embodiment of the present invention;
Fig. 24 is a diagram showing the construction of the receiver section of a radar apparatus having active array antennas;
Fig. 25 is a diagram showing the construction of the receiver section of a DBFN (beam-scan) radar apparatus;
Fig. 26 is a diagram showing the construction of the receiver section of a DBFN (multiple-beam) radar apparatus; and
Fig. 27 is a diagram showing the construction of the receiver section of a monopulse radar apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

(A) Overview of the invention

(a) Overview of first aspect (see Fig. 1)

[0027] The present invention provides an array antenna radar apparatus having a plurality of antennas $11_1 \sim 11_N$, adjusting circuits $21_1 \sim 21_N$, $22_1 \sim 22_N$ provided in correspondence with respective ones of the antennas $11_1 \sim 11_N$ for adjusting phase or amplitude of input signals applied thereto, and a combining circuit 25 for combining signals that have been adjusted in phase or amplitude by the adjusting circuits. The radar apparatus further includes (1) a front end 13 provided commonly for the antennas $11_1 \sim 11_N$ for amplifying signals, which have been received by the antennas, successively applied thereto, and for frequency-converting the amplified signals to intermediate-frequency signals, (2) a first switch 12 for cyclically connecting the antennas $11_1 \sim 11_N$ to the front end 13 at a prescribed switching frequency, (3) frequency converters $19_1 \sim 19_N$ provided in correspondence with respective ones of the antennas $11_1 \sim 11_N$ for frequency-converting the intermediate-frequency signals output by the front end 13 to other intermediate-frequency signals or baseband signals at the above-mentioned switching frequency, (4) a second

tion pattern is formed at the time of transmission.

[0035] If this arrangement is adopted, only one front end need be provided for the antennas, each antenna can be used for both transmission and reception and a desired antenna radiation pattern is formed at the time of transmission.

(g) Overview of seventh aspect (see Fig. 10)

[0036] The present invention according to this aspect provides an array antenna radar apparatus having the plurality of antennas $11_1 \sim 11_N$, the adjusting circuits $21_1 \sim 21_N$, $22_1 \sim 22_N$ provided in correspondence with respective ones of the antennas $11_1 \sim 11_N$ for adjusting phase or amplitude of input signals applied thereto, and the combining circuit 25 for combining signals that have been adjusted in phase or amplitude by the adjusting circuits. The radar apparatus further includes (1) a front end 13 provided commonly for the antennas $11_1 \sim 11_N$ for amplifying signals, which have been received by the antennas, successively applied thereto, and for frequency-converting the amplified signals to intermediate-frequency signals, (2) the switch 12 for cyclically connecting the antennas $11_1 \sim 11_N$ to the front end 13 at a prescribed switching frequency, (3) A/D converters $20_1 \sim 20_N$ provided in correspondence with respective ones of the antennas $11_1 \sim 11_N$ for A/D-converting signals output by the front end, and (4) a sampling control circuit 31 for causing an A/D converter that corresponds to an ith antenna to sample and A/D-convert an output signal of the front end when the signal received by the ith antenna is entering the front end, wherein a target lying in a desired direction is detected by adjusting the phase or amplitude of an output signal from each A/D converter and combining the signals that result.

[0037] If this arrangement is adopted, the outputs of the A/D converters become equal to what would be obtained by sampling the outputs of the frequency converters $19_1 \sim 19_N$ of Fig. 1. This makes it possible to eliminate the second switch and frequency converters of the radar apparatus shown in Fig. 1, thereby reducing the number of component parts.

(h) Overview of eighth aspect (see Fig. 12)

[0038] The radar apparatus according to this aspect of the present invention has delay circuits $32_1 \sim 32_N$ provided at the inputs to the A/D converters $20_1 \sim 20_N$ for delaying the A/D conversion timing. By providing the delay circuits, received signals sampled at identical timings can be converted to digital data and processed. This makes it possible to improve the accuracy of target detection.

(i) Overview of ninth aspect (see Fig. 13)

[0039] The radar apparatus according to this aspect of the present invention has the plurality of antennas $11_1 \sim 11_N$, adjusting circuits 23, 24 provided for commonly for the antennas $11_1 \sim 11_N$ for adjusting phase or amplitude of input signals applied thereto, and a combining circuit for combining signals that have been adjusted in phase or amplitude by the adjusting circuits. This array antenna radar apparatus includes (1) a front end 13 provided commonly for the antennas $11_1 \sim 11_N$ for amplifying signals, which have been received by the antennas, successively applied thereto, and for frequency-converting the amplified signals to intermediate-frequency signals, (2) the switch 12 for cyclically connecting the antennas $11_1 \sim 11_N$ to the front end 13 at a prescribed switching frequency, (3) an A/D converters 20 for A/D-converting the intermediate-frequency signal output by the front end 13, and (4) means 15 ~ 16, 41 for causing the A/D converter 20 to sample and A/D convert the output of the front end 13 at a frequency obtained by multiplying the switching frequency by the number of the plurality of antennas, and for storing, as a signal corresponding to an ith antenna, an A/D converted output prevailing when the signal received by the ith antenna is entering the front end, wherein a target lying in a desired direction is detected by adjusting the phase or amplitude of an output signal, which corresponds to each antenna, from the A/D converter 20, and combining the signals that result.

[0040] If this arrangement is adopted, only one A/D converter and one phase/amplitude adjusting means need be provided commonly for the antennas. This makes it possible to reduce the number of component parts even further and to further simply the arrangement.

(j) Overview of tenth aspect (see Fig. 15)

[0041] This aspect of the present invention provides a monopulse radar apparatus having two antennas 51_1, 51_2, comparators 61, 62 for comparing the phases or amplitudes of reflected signals that arrive at the two antennas, and an arrival-direction estimating unit 63 for estimating the arrival direction of a reflected signal based upon the results of the comparison. The radar apparatus further includes (1) a front end 53 provided commonly for the antennas 51_1, 51_2 for amplifying signals, which have been received by the antennas, successively applied thereto, and for frequency-converting the amplified signals to intermediate-frequency signals, (2) a first switch 52 for alternately connecting the antennas 51_1, 51_2 to the front end 53 at a prescribed switching frequency, (3) frequency converters 59_1, 59_2 provided in correspondence with respective ones of the antennas 51_1, 51_2 for frequency-converting the intermediate-frequency signals output by the front end 13 to other intermediate-frequency signals or baseband signals at the above-mentioned switching frequency, (4) a second switch 54, which is switched in synchronization with the first switch 52, for connecting an output of the front end 53 to a frequency converter that corresponds

puts of the corresponding frequency converters to digital data. Phase shifters $21_1 \sim 21_N$ apply phase shifts of predetermined amounts $\phi_1 \sim \phi_N$ to inputs applied to them. Amplitude adjusters $22_1 \sim 22_N$ adjust the amplitudes of the signals output by the corresponding phase shifters. A phase control circuit 23 and an amplitude control circuit 24 decide phase shifts of amounts $\phi_1 \sim \phi_N$ and amplitude adjustment values $A_1 \sim A_N$ so as to perform a phase adjustment and amplitude adjustment conforming to the desired beam pattern, and input $\phi_1 \sim \phi_N$ and $A_1 \sim A_N$ to the respective phase shifters $21_1 \sim 21_N$ and respective amplitude adjusters $22_1 \sim 22_N$. An adder 25 combines the output signals from the amplitude adjusters $22_1 \sim 22_N$ and outputs the resulting signal.

(b) Operation

[0051] The RF signals received by the antennas $11_1 \sim 11_N$ are cyclically selected and input to the front end 13 by the first switch 12 at the frequency fs, and the output of the front end 13 is selected by the second switch 14, which performs a switching operation in synchronization with the first switch 12. More specifically, the second switch 14 performs a switching operation in sync with the first switch 12 so that when a signal received by an ith antenna 11_i is entering the front end 13, the output of the front end 13 is connected to the frequency converter 19_i that corresponds to the ith antenna.

[0052] Intermittently selecting, at the frequency fs, the RF signals (carrier signals) received by the antennas $11_1 \sim 11_N$ is equivalent to modulating the amplitude of the RF signal (carrier signal) at the frequency fs. Accordingly, frequency components indicated by the spectrum of Fig. 3A are generated by the switching operation of the first and second switches 12, 14, where fc represents the frequency of the carrier signal (RF signal), fb the frequency of the baseband signal carried by the carrier signal, f_{LO} (= fc - fb) the oscillation frequency of the local oscillation signal and fs the switching frequency. If the local oscillation signal of frequency f_{LO} (= fc - fb) is mixed with this signal by the mixer 13c, a signal having the spectrum distribution shown in Fig. 3B is generated. This signal is input to the IF filters $17_1 \sim 17_N$.

[0053] The IF filters $17_1 \sim 17_N$ each select and output an IF signal (a signal having an intermediate frequency of fs ± fb) contained in the intermediate-frequency band indicated by the dashed line in Fig. 3B. The frequency converters $19_1 \sim 19_N$ mix the local oscillation signal of frequency fs output by the filter 18 with the signals that enter from the IF filters $17_1 \sim 17_N$, respectively, demodulate the baseband signal shown in Fig. 3C and output the resulting signal.

[0054] The A/D converters $20_1 \sim 20_N$ convert the baseband signals demodulated by the frequency converters $19_1 \sim 19_N$ to digital data. The phase control circuit 23 and amplitude control circuit 24 decide the phase shifts of amounts $\phi_1 \sim \phi_N$ and the amplitude adjustment values $A_1 \sim A_N$ so as to perform a phase adjustment and amplitude adjustment conforming to the desired beam pattern, i.e., so as to detect a target in a desired direction, and set $\phi_1 \sim \phi_N$ and $A_1 \sim A_N$ in the respective phase shifters $21_1 \sim 21_N$ and respective amplitude adjusters $22_1 \sim 22_N$.

[0055] The phase shifters $21_1 \sim 21_N$ and amplitude adjusters $22_1 \sim 22_N$ subject the digital data that has entered from the A/D converters $20_1 \sim 20_N$ to the phase shifts $\phi_1 \sim \phi_N$ and amplitude adjustment values $A_1 \sim A_N$, and the adder 25 combines the signals output by the amplitude adjusters $22_1 \sim 22_N$ and inputs the result to a processing unit (not shown), which is the next stage. The processing unit executes target detection processing. By thenceforth repeating the foregoing control while successively changing the search direction, the direction in which the target lies can be detected.

[0056] Thus, in accordance with the first embodiment, only the one front end 13 need be provided commonly for the antennas in a radar apparatus composed of an array antenna. This makes it possible to simplify the apparatus and or dispense with the compensating means and adjustment circuits required in the prior art.

(c) First modification

[0057] Fig. 4 is a diagram showing a modification of amplitude control according to the first embodiment. Components identical with those of the first embodiment shown in Fig. 1 are designated by like reference characters. In the first embodiment, amplitude is adjusted by causing the amplitude adjustment values $A_1 \sim A_N$ to act upon the digital data of the baseband. In the first modification of Fig. 4, however, amplitude is adjusted by adjusting the ON times of the first and second switches 12, 14.

[0058] If amplitude weightings for the amplitude adjusters $22_1 \sim 22_N$ are entered as inputs, as shown in Fig. 5, an amplitude control circuit 24' converts these amplitude weighting values to switch ON times $W_1 \sim W_N$ and inputs the switch ON times to a switching controller 16'. As a result, the switch controller 16' generates antenna selection signals $S_1' \sim S_N'$ of respective pulse widths $W_1 \sim W_N$ at the frequency fs, as illustrated in Fig. 6. On the basis of the antenna selection signals $S_1' \sim S_N'$, the first and second switches 12, 14 control the time during which each antenna is selected and connected to the input side of the front end 13 and the time during which the output of the front end 13 is input to the frequency converters. Since pulse width and amplitude are equivalent, pulse width is adjusted in dependence upon the pulse widths $W_1 \sim W_N$. In other words, the amplitude control circuit 24' adjusts the lengths of time $W_1 \sim W_N$ during which the antennas $11_1 \sim 11_N$ are connected to the front end 13 and the output of the front end 13 is connected to the frequency converters $19_1 \sim 19_N$ that correspond to these antenna in

the second embodiment shown in Fig. 10 are designated by like reference characters. This modification differs from the second embodiment in that the delay circuits 32_1 ~ 32_N are provided between the front end 13 and respective ones of the A/D converters 20_1 ~ 20_N. Providing the delay circuits 32_1 ~ 32_N makes it possible to match the sampling and A/D conversion timings of the A/D converters 20_1 ~ 20_N, thereby improving the accuracy of target detection.

(c) Second modification

[0071] Fig. 13 illustrates a second modification of the second embodiment, in which components identical with those of the second embodiment shown in Fig. 10 are designated by like reference characters. Fig. 14 is a timing chart useful in describing the operation of the second modification.

[0072] The second modification differs from the second embodiment in the following respects:

(1) One A/D converter 20 is provided commonly for the antennas.
(2) The A/D converter 20 samples and A/D-converts the output at a sample clock having a frequency the same as the sampling frequency N • fs of the switch 12.
(3) A/D-converted data from the A/D converter 20 enters a data rearranging unit 41 at each sampling clock.
(4) The data rearranging unit 41 rearranges the successively entered digital data in memory in the following manner: first data of the first antenna 11_1 → first data of the second antenna 11_2 → • • • first data of the Nth antenna 11_N → second data of the first antenna 11_1 → second data of the second antenna 11_2 → • • • second data of the Nth antenna 11_N → • • •.
(5) The data rearranging unit 41, phase control circuit 23 and amplitude control circuit 24 are constituted by a DSP (Digital Analog Processor) which, by executing DSP processing, subjects the signals received by the antennas to the phase shifts ϕ_1 ~ ϕ_N and amplitude adjustments A_1 ~ A_N and combines the resulting signals.

[0073] In the second modification, the phase-shift quantities ϕ_1 ~ ϕ_N and amplitude adjustment values A_1 ~ A_N of the received signals from the antennas are controlled so as to form the desired antenna radiation pattern, the resulting signals are combined and the signal resulting from the combination is output, thereby making it possible to detect a target from any direction.

(D) Third embodiment

(a) Configuration

[0074] Fig. 15 shows a monopulse radar apparatus, particularly the receiver section thereof, according to a third embodiment of the present invention.

[0075] The apparatus includes first and second antennas 51_1, 51_2, which receive reflected electric power from a target, and the first switch 52 for alternately selecting, and connecting to the front end 53, the antennas 51_1, 51_2 at a frequency fs that is much higher than a baseband frequency fb. The front end 53 is provided commonly for the first and second antennas 51_1, 51_2 and has (1) an RF amplifier 53a for low-noise amplification of the signal received by each antenna, (2) a local oscillator 53b for outputting a local oscillation signal of frequency f_{LO} (= fc - fb), where fc represents a carrier frequency and fb the baseband frequency, and (3) a mixer (frequency converter) 53c for mixing the local oscillation signal of frequency f_{LO} (= fc - fb) with the RF signal output by the RF amplifier 53a and frequency-converting the RF signal to an intermediate-frequency signal.

[0076] The second switch 54, which is switched in synchronization with the first switch 52, connects the output of the front end 53 to the frequency converter that corresponds to the first or second antenna when the signal received by the first or second antenna is entering the front end 53. An oscillator 55 outputs a signal having a frequency of 2 • fs. A switch controller 56 receives the signal of frequency 2 • fs as an input and outputs antenna selection signals S_1, S_2 (see Fig. 2, where N = 2) to control the first and second switches 52, 54.

[0077] The IF filters 57_1, 57_2, which are provided for respective ones of the antennas 51_1, 51_2, remove higher harmonics and low-frequency components from the signal that enters from the front end 53 and pass the desired intermediate-frequency components. A low-pass filter 58 converts a rectangular wave having the frequency of fs to a sinusoidal local oscillation signal and outputs this signal to the mixers (frequency converters) 59_1, 59_2. The latter mix the local oscillation signal (the low-pass filter output) with IF signals from the corresponding IF filters 57_1, 57_2 to effect a frequency conversion to other intermediate-frequency signals or baseband signals.

[0078] The A/D converters 60_1, 60_2 convert the outputs of the corresponding frequency converters to digital data. The phase comparator circuit 61 compares the phases of the signals received by the two antennas, and the amplitude comparator circuit 62 compares the amplitudes of the signals received by the two antennas. The arrival-direction estimating unit 63 estimates the direction of a target (the signal arrival direction) based upon a detected phase difference or amplitude difference. It should be noted that both a phase comparison

the first embodiment shown in Fig. 1 are designated by like reference characters. In the first embodiment, the antennas $11_1 \sim 11_N$ are used exclusively for reception. According to the fourth embodiment, however, the antennas $11_1 \sim 11_N$ are used for both transmission and reception.

[0089] The apparatus shown in Fig. 17 includes the transmitter circuit 71 and the third switch 72 that alternately connects whichever of the antennas $11_1 \sim 11_N$ has been selected by the first switch 12 to the transmitter circuit 71 and front end 13.

[0090] The first switch 12 cyclically selects the antennas $11_1 \sim 11_N$ by the antenna selection signals $S_1 \sim S_N$, as indicated by the dashed lines in Fig. 18, and connects the selected antenna to the third switch 72. The third switch 72 alternately connects the antenna selected by the first switch 12 to the transmitter circuit 71 and front end 13, thereby using this antenna for both transmission and reception.

[0091] As a result of this arrangement, the antennas can be selected cyclically and used alternately for transmission/reception in the following manner: (1) transmission/reception is performed by the first antenna 11_1, (2) then by the second antenna 11_2, (3) then by the third through Nth antennas $11_3 \sim 11_N$ in succession, and (4) then again by the first antenna 11_1 and so on. Accordingly, it suffices to provide only the single front end 13 commonly for the antennas $11_1 \sim 11_N$ and, moreover, each antenna can be used for both transmission and reception.

(F) Fifth embodiment

[0092] In the fourth embodiment, all of the antennas are used for both transmission and reception. However, there are instances where only some are used for both transmission and reception and the others are used solely for reception. Fig. 19 is a diagram showing the construction of a radar apparatus according to a fifth embodiment in which only the first antenna 11_1 is used for both transmission and reception and the other antennas $11_2 \sim 11_N$ are used exclusively for reception. Components identical with those of the first embodiment shown in Fig. 1 are designated by like reference characters.

[0093] The apparatus shown in Fig. 19 includes the transmitter circuit 71 and the third switch 73 that connects the transmitter circuit 71 to the first antenna 11_1 in alternation with the cyclic connecting of the antennas $11_1 \sim 11_N$ to the front end 13 by the first switch 12. More specifically, as illustrated in the time chart of Fig. 20, the antennas $11_1 \sim 11_N$ are cyclically connected to the front end 13, so as to be used for reception, by the first switch 12 based upon the antenna selection signals $S_1 \sim S_N$ having the switching frequency fs. This operation is the reception cycle. The first antenna 11_1, which is for both transmission and reception, is connected to the transmitter circuit 71, so as to be used for transmission, based upon a transmitter-circuit selection signal TR having the frequency $N \cdot fs$. This operation is the transmission cycle. The switch controller 16 generates the antenna selection signals $S_1 \sim S_N$ and the transmitter-circuit selection signal TR in such a manner that reception and transmission are performed alternately.

[0094] As a result, only the first antenna 11_1 is used for both transmission and reception and the other antennas can be used exclusively for reception in the following manner: (1) transmission and reception are performed by the first antenna $11_1 \rightarrow$ (2) transmission is performed by the first antenna 11_1 and reception by the second antenna $11_2 \rightarrow \cdots$ (3) transmission is performed by the first antenna 11_1 and reception by the Nth antenna $11_N \rightarrow$ (4) transmission and reception are performed by the first antenna 11_N and so on. Only one front end need be provided for the antennas. It should be noted that although one antenna is used for both transmission and reception in this embodiment, two or more antenna can be adopted for transmission and reception if desired.

(G) Sixth embodiment

[0095] Fig. 21 is a diagram showing the construction of a radar apparatus according to a sixth embodiment in which the antennas are used for both transmission and reception. Components identical with those of the first embodiment shown in Fig. 1 are designated by like reference characters. In the first embodiment, all of the antennas $11_1 \sim 11_N$ are used exclusively for reception. In the sixth embodiment, however, all of the antennas $11_1 \sim 11_N$ are used for both transmission and reception.

[0096] The apparatus shown in Fig. 21 includes the transmitter circuit 71, the third switches $75_1 \sim 75_N$ provided between the respective antennas $11_1 \sim 11_N$ and the first switch 12 for selectively connecting the antennas $11_1 \sim 11_N$ to the first switch 12 and the side of the transmitter circuit 71, and a phase/amplitude adjustment circuit 76 for adjusting the phase or amplitude of a transmission signal input to each antenna. In the transmission cycle, the third switches $75_1 \sim 75_N$ connect the phase/amplitude adjustment circuit 76 to all of the antennas $11_1 \sim 11_N$ simultaneously so that a transmission signal that has undergone a predetermined phase or amplitude correction will enter each of the antennas, whereby radio waves having the desired antenna radiation pattern are emitted.

[0097] As illustrated in the time chart of Fig. 22, the switch controller 16 generates the antenna selection signals $S_1 \sim S_N$ and the transmitter-circuit selection signal TR in such a manner that reception and transmission are performed alternately. More specifically, the first switch 12 and the third switches $75_1 \sim 75_N$ cooperate to input phase- or amplitude-adjusted transmission signals to all of the antennas $11_1 \sim 11_N$ (this is the transmission cycle) and to form and emit the desired antenna radiation pattern and cyclically connect the

A/D converter is provided commonly for all of the antennas and the A/D converter is used for sampling/AD conversion of each antenna reception signal in time-shared fashion. This makes possible a major reduction in the number of parts used, thereby simplifying the apparatus.

[0112] In accordance with the present invention, only a single front end need be provided commonly for each of the two antennas of a monopulse radar apparatus. This makes it possible to simplify the arrangement and to dispense with compensating means and adjustment circuits required in the prior art.

[0113] In accordance with the present invention, the monopulse radar apparatus is so adapted that if the two antennas of the apparatus are used for both transmission and reception, the antennas are selected alternately and the selected antenna is connected to a transmitter circuit and front end in alternating fashion. As a result, only a single front end need be provided commonly for each of the antennas of the radar apparatus and, moreover, each antenna can be used for both transmission and reception.

[0114] In accordance with the present invention, the monopulse radar apparatus is so adapted that an A/D converter corresponding to each antenna samples and A/D-converts the signal, which has been received by this antenna, at an antenna selection timing. This makes it possible to eliminate a second switch and frequency converters, thereby reducing the number of component parts.

[0115] As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.

Claims

1. An array antenna radar apparatus having a plurality of antennas, adjusting circuits provided in correspondence with respective ones of the antennas for adjusting phase or amplitude of input signals to the adjusting circuits, and a combining circuit for combining signals that have been adjusted in phase or amplitude by the adjusting circuits, the radar apparatus comprising:

    a front end provided commonly for the antennas for amplifying signals, which have been received by the antennas, successively input thereto, and for frequency-converting the amplified signals to intermediate-frequency signals;
    a first switch for cyclically connecting the antennas to said front end at a prescribed switching frequency;
    frequency converters provided in correspondence with respective ones of the antennas for frequency-converting the intermediate-frequency signals output by said front end to other intermediate-frequency signals or baseband signals at the said switching frequency;
    a second switch, which is switched in synchronization with said first switch, for connecting the output of said front end to whichever of said frequency converters corresponding to an ith antenna when the signal received by the ith antenna is entering said front end; and
    intermediate-frequency filters provided between said second switch and respective ones of said frequency converters;
    wherein a target lying in a desired direction is detected by adjusting the phase or amplitude of an output from each frequency converter and combining the signals that result.

2. The apparatus according to claim 1, further comprising a local oscillator for outputting a local oscillation signal having a frequency identical with the switching frequency; and

    adjusting circuits each for adjusting phase or amplitude of the local oscillation signal being provided between said local oscillator and respective ones of said frequency converters;
    wherein the local oscillation signals that have been adjusted in phase or amplitude by each of said adjusting circuits is input to the respective frequency converters, and each frequency converter outputs a signal whose phase or amplitude has been adjusted.

3. The apparatus according to claim 1, wherein an amplitude adjustment is applied to the outputs of said frequency converters by adjusting lengths of time during which the antennas are connected to said front end and lengths of time during the output of said front end is connected to the frequency converters that correspond to said antennas.

4. The apparatus according to claim 1, wherein each of the antennas is used for both transmission and reception, and the apparatus further comprises a third switch for alternately connecting an antenna, which has been selected by said first switch, to a transmitter circuit and said front end.

5. The apparatus according to claim 1, wherein at least one of the antennas is used for both transmission and reception and the other antennas are used exclusively for reception, and the apparatus further comprises a third switch for connecting, in alternation with cyclic connecting of each of the antennas to said front end, a transmitter circuit to said antenna that is for both transmission and reception.

ones of said frequency converters;
wherein arrival direction of a reflected signal is estimated by comparing phases or amplitudes of output signals from said frequency converters.

11. The apparatus according to claim 10, wherein the two antennas are used for both transmission and reception, and the apparatus further comprises a third switch for alternately connecting an antenna, which has been selected by said first switch, to a transmitter circuit and said front end.

12. A monopulse radar apparatus having two antennas, comparators for comparing phases or amplitudes of a reflected signal that arrives at the two antennas, and an arrival-direction estimating unit for estimating the arrival direction of the reflected signal based upon the results of the comparison, the apparatus comprising:

a front end provided commonly for the antennas for amplifying signals, which have been received by the antennas, successively input thereto, and for frequency-converting the amplified signals to intermediate-frequency signals;
a switch for alternately connecting the antennas to said front end at a prescribed switching frequency;
A/D converters provided in correspondence with respective ones of the antennas and connected to said front end for A/D-converting signals output by said front end; and
a sampling control circuit for causing whichever of said A/D converters corresponding to an ith antenna to sample and A/D-convert the output signal of said front end when the signal received by the ith antenna is entering said front end;
wherein output signals of said A/D converters are compared in phases or amplitudes thereof to estimate the arrival direction of a reflected signal.

FIG.2

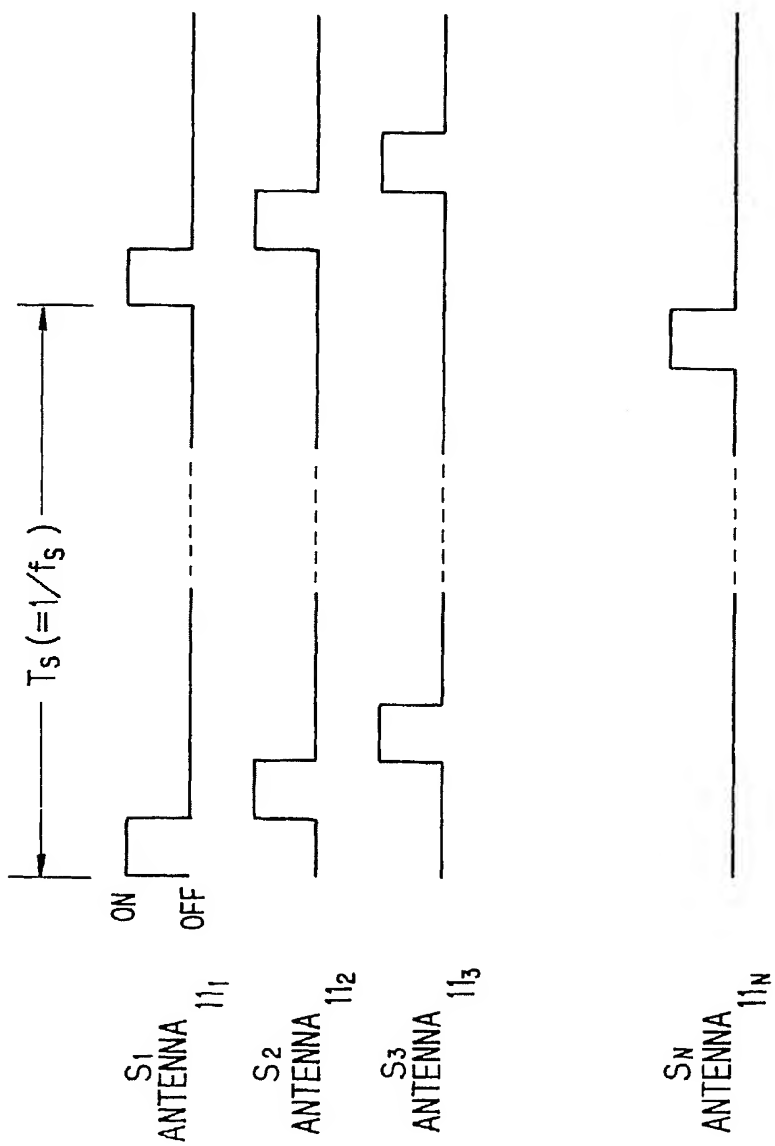

Ts (=1/fs)
ON
OFF
S1 ANTENNA 11_1
S2 ANTENNA 11_2
S3 ANTENNA 11_3
SN ANTENNA 11_N

FIG. 4

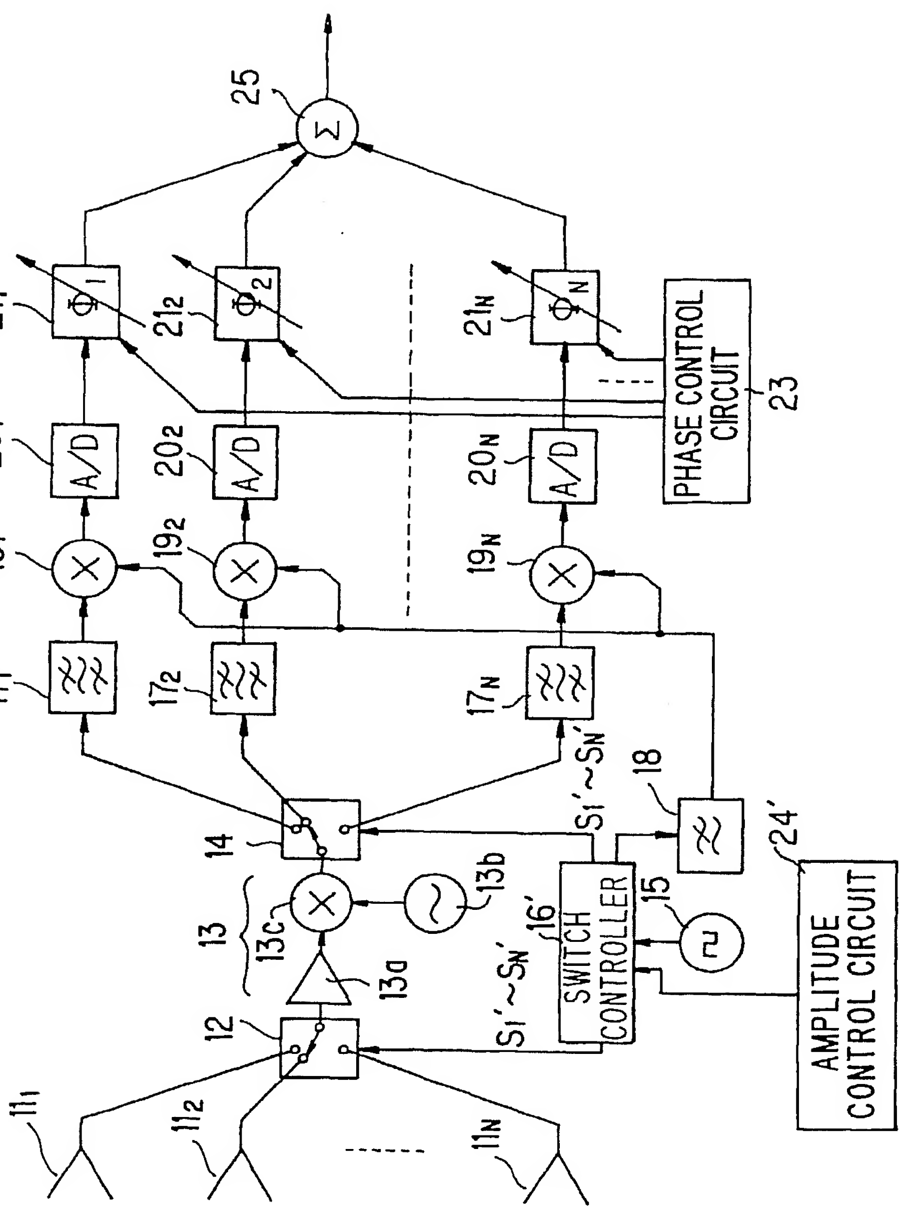

PHASE CONTROL CIRCUIT
SWITCH CONTROLLER
AMPLITUDE CONTROL CIRCUIT
A/D
A/D
A/D

FIG.6

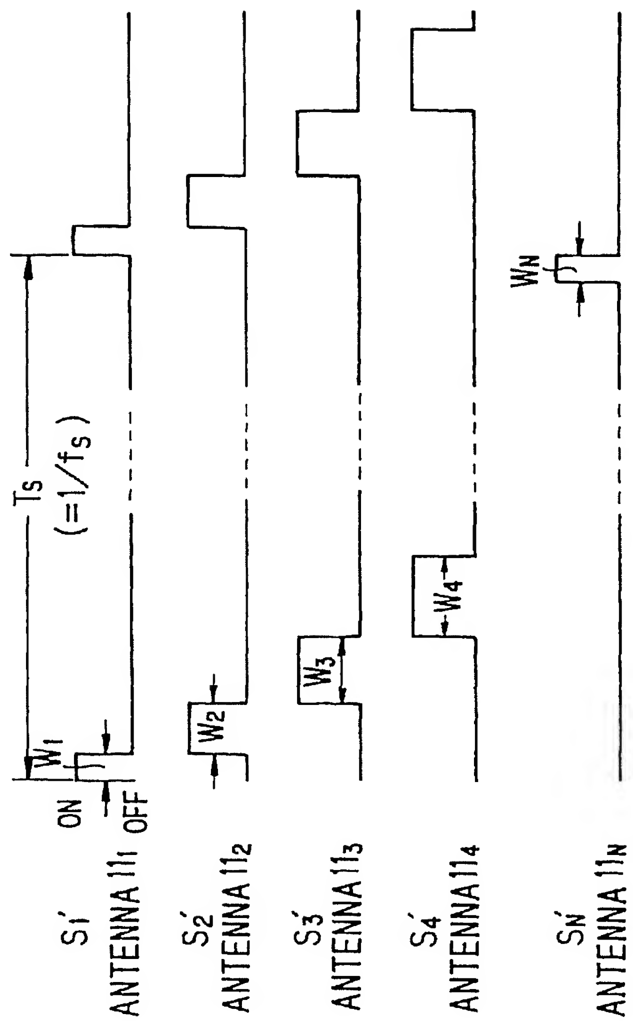
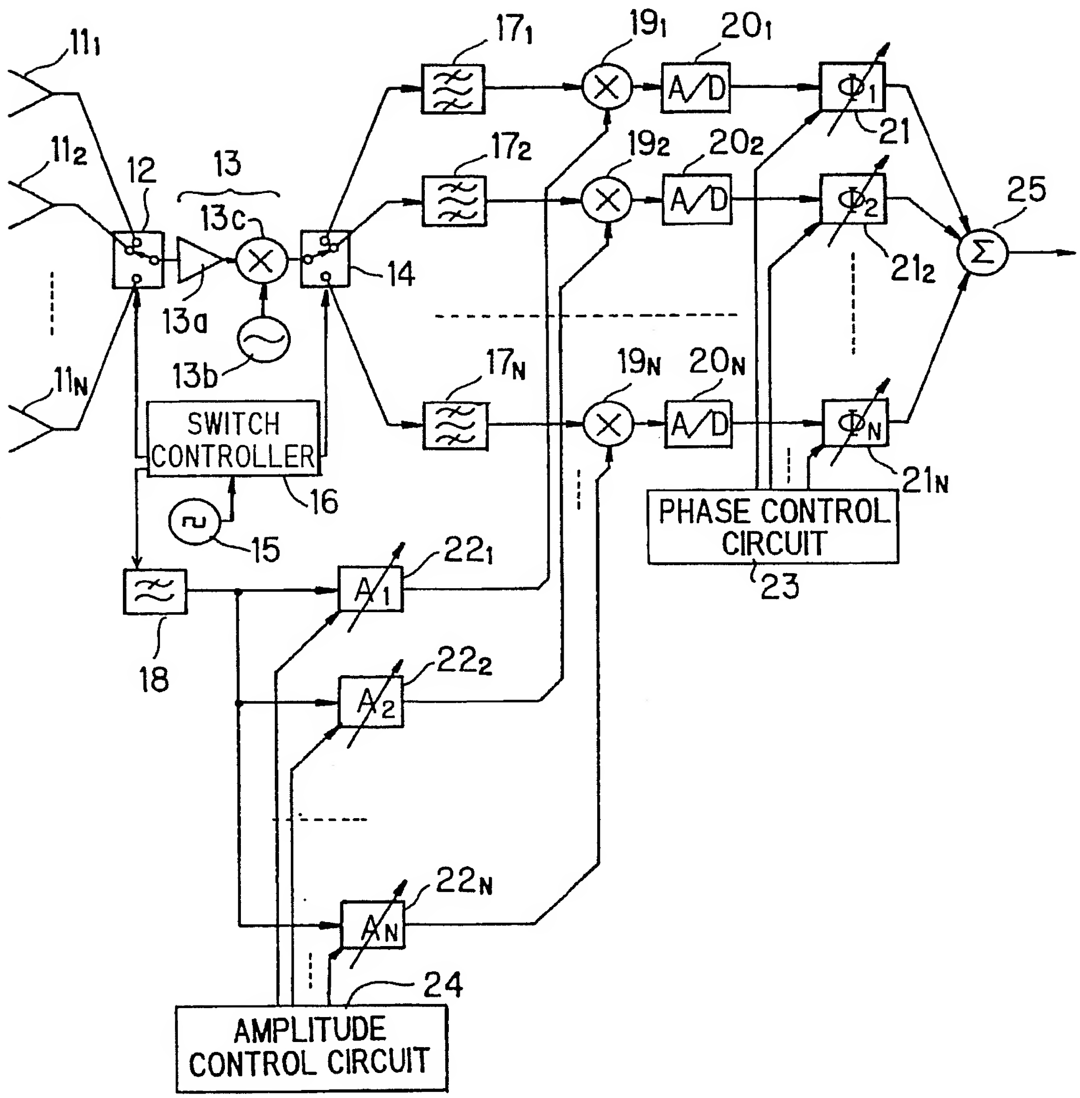

S1'
ANTENNA 11₁
ON
OFF
W1
Ts
(=1/fs)
S2'
ANTENNA 11₂
W2
S3'
ANTENNA 11₃
W3
S4'
ANTENNA 11₄
W4
SN'
ANTENNA 11N
WN

FIG. 8



11₁
11₂
11N
12
13
13c
13a
13b
14
17₁
17₂
17N
19₁
19₂
19N
20₁
20₂
20N
A/D
A/D
A/D
Φ1
Φ2
ΦN
21
21₂
21N
25
Σ
SWITCH CONTROLLER
16
15
18
A1
A2
AN
22₁
22₂
22N
PHASE CONTROL CIRCUIT
23
AMPLITUDE CONTROL CIRCUIT
24

FIG.10

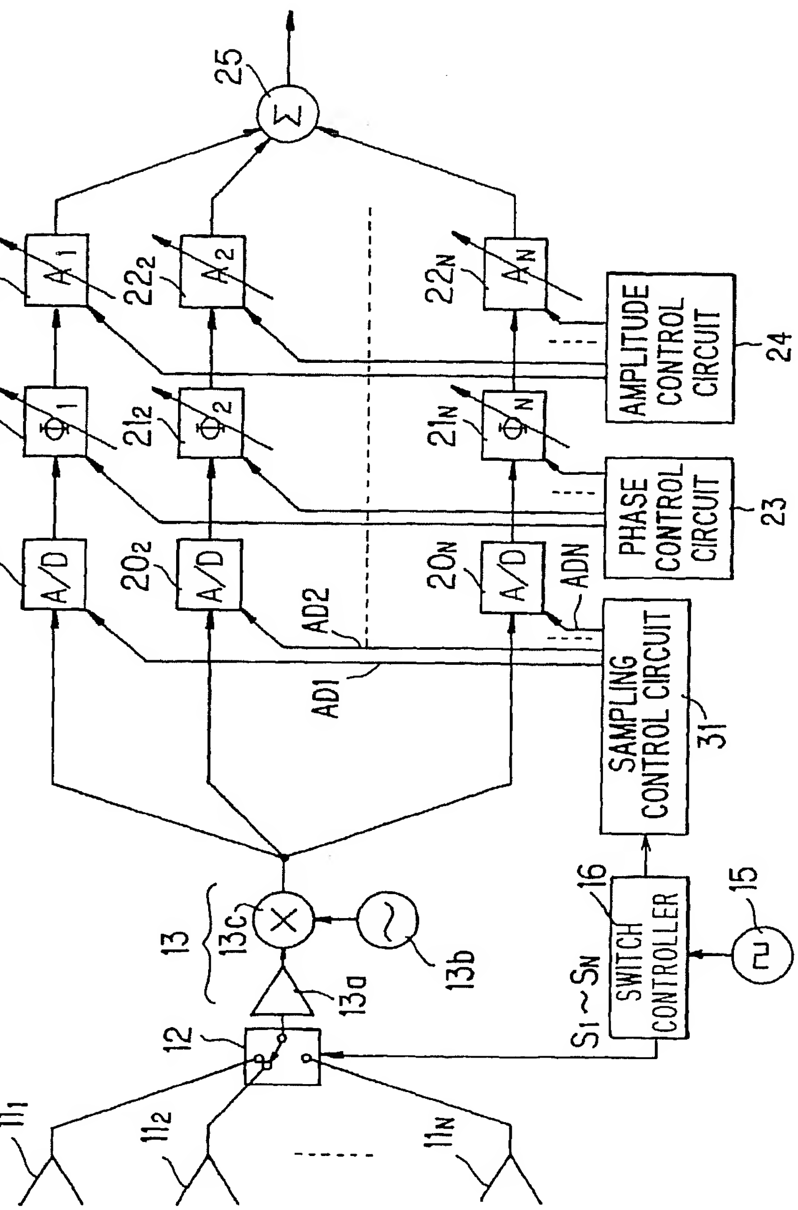

SWITCH CONTROLLER
SAMPLING CONTROL CIRCUIT
PHASE CONTROL CIRCUIT
AMPLITUDE CONTROL CIRCUIT
A/D
AD1
AD2
ADN
S1～SN

FIG.12

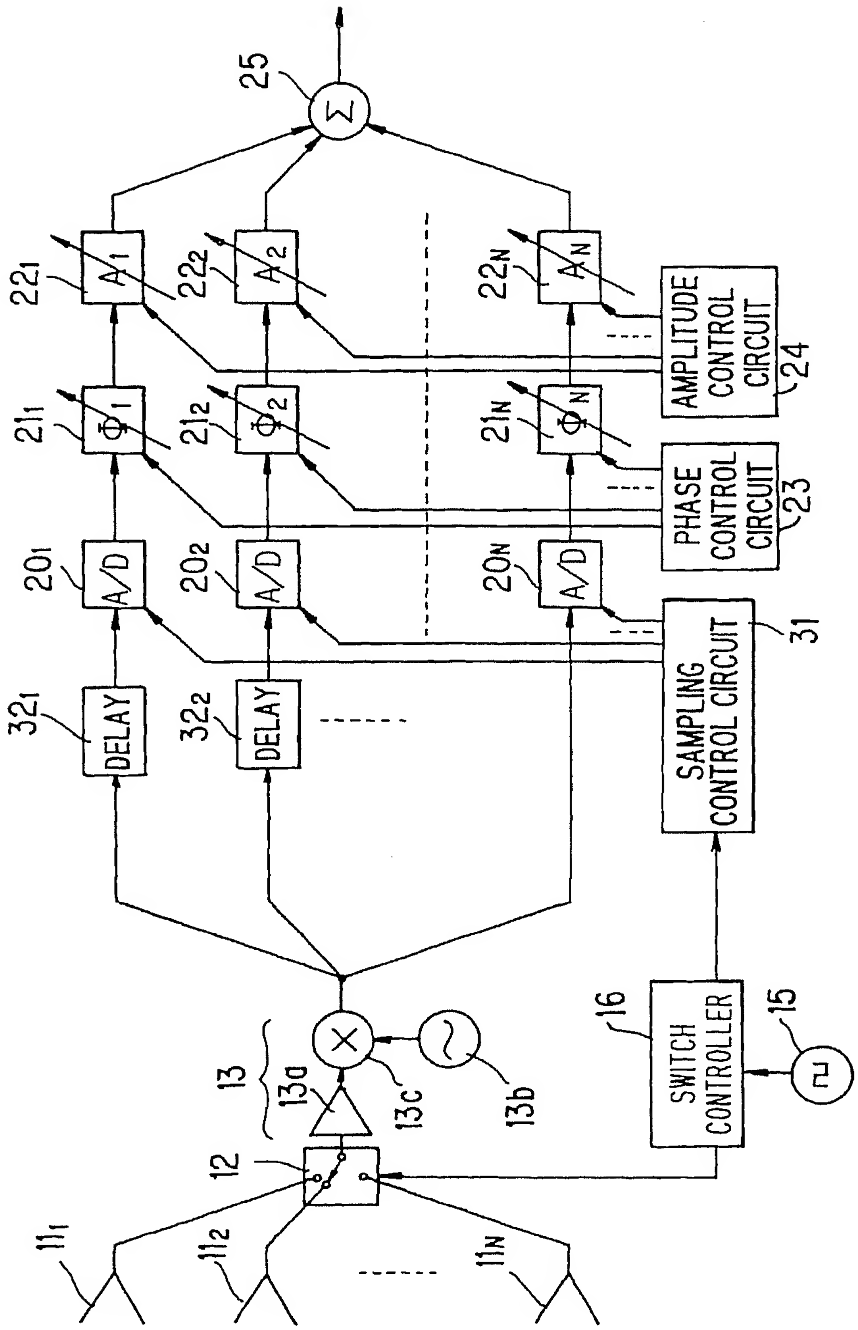

11₁
11₂
11N
12
13
13a
13b
13c
15
16
SWITCH CONTROLLER
SAMPLING CONTROL CIRCUIT
31
32₁
32₂
DELAY
DELAY
20₁
20₂
20N
A/D
A/D
A/D
21₁
21₂
21N
PHASE CONTROL CIRCUIT
23
22₁
22₂
22N
AMPLITUDE CONTROL CIRCUIT
24
25

FIG.14

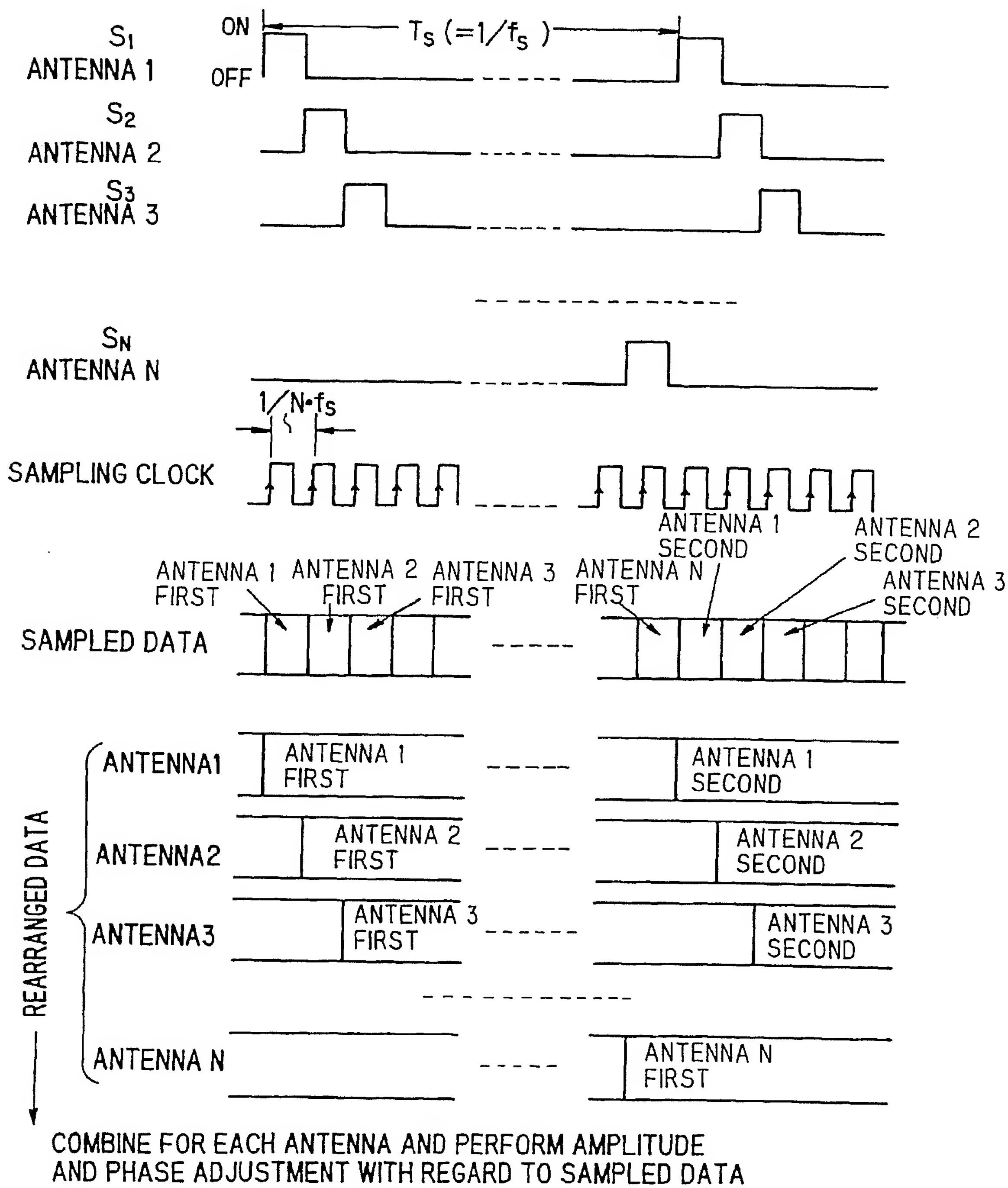

S1
ANTENNA 1
ON
OFF
Ts (=1/fs)
S2
ANTENNA 2
S3
ANTENNA 3
SN
ANTENNA N
1/N•fs
SAMPLING CLOCK
ANTENNA 1 FIRST
ANTENNA 2 FIRST
ANTENNA 3 FIRST
ANTENNA N FIRST
ANTENNA 1 SECOND
ANTENNA 2 SECOND
ANTENNA 3 SECOND
SAMPLED DATA
REARRANGED DATA
ANTENNA1
ANTENNA2
ANTENNA3
ANTENNA N
ANTENNA 1 FIRST
ANTENNA 1 SECOND
ANTENNA 2 FIRST
ANTENNA 2 SECOND
ANTENNA 3 FIRST
ANTENNA 3 SECOND
ANTENNA N FIRST
COMBINE FOR EACH ANTENNA AND PERFORM AMPLITUDE
AND PHASE ADJUSTMENT WITH REGARD TO SAMPLED DATA

FIG.16

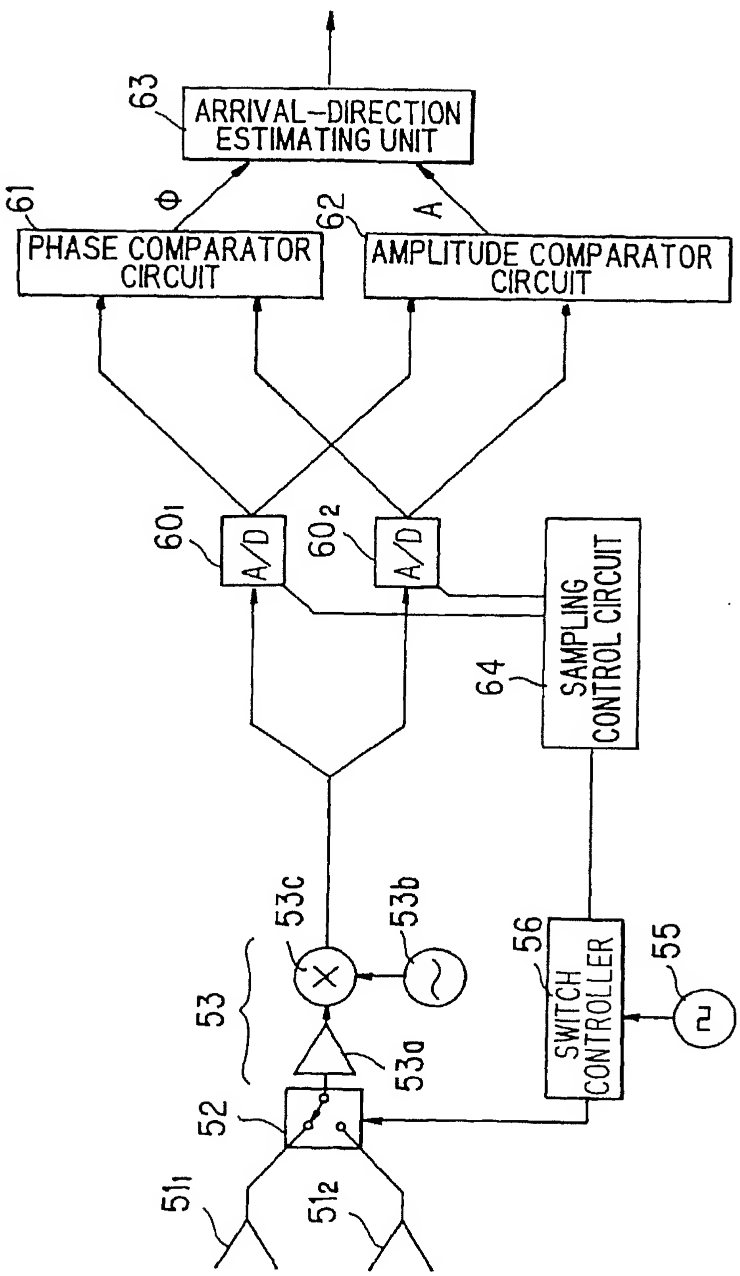

63
ARRIVAL-DIRECTION ESTIMATING UNIT
61
PHASE COMPARATOR CIRCUIT
Φ
62
AMPLITUDE COMPARATOR CIRCUIT
A
60_1
A/D
60_2
A/D
64
SAMPLING CONTROL CIRCUIT
53c
53b
53
53a
52
51_1
51_2
56
SWITCH CONTROLLER
55

FIG.18

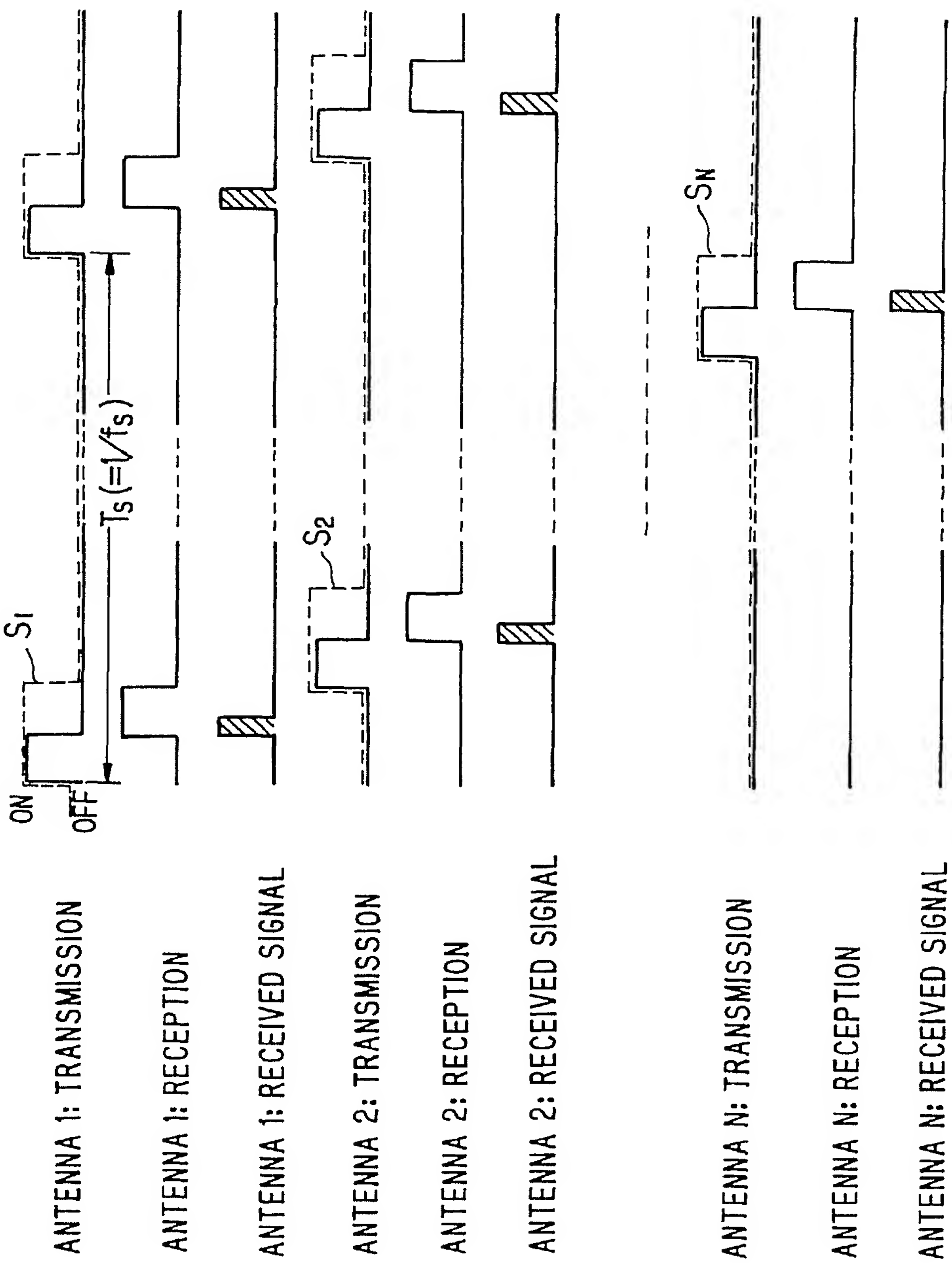

ANTENNA 1: TRANSMISSION
ANTENNA 1: RECEPTION
ANTENNA 1: RECEIVED SIGNAL
ANTENNA 2: TRANSMISSION
ANTENNA 2: RECEPTION
ANTENNA 2: RECEIVED SIGNAL
ANTENNA N: TRANSMISSION
ANTENNA N: RECEPTION
ANTENNA N: RECEIVED SIGNAL
ON
OFF
S1
S2
SN
Ts(=1/fs)

FIG.20

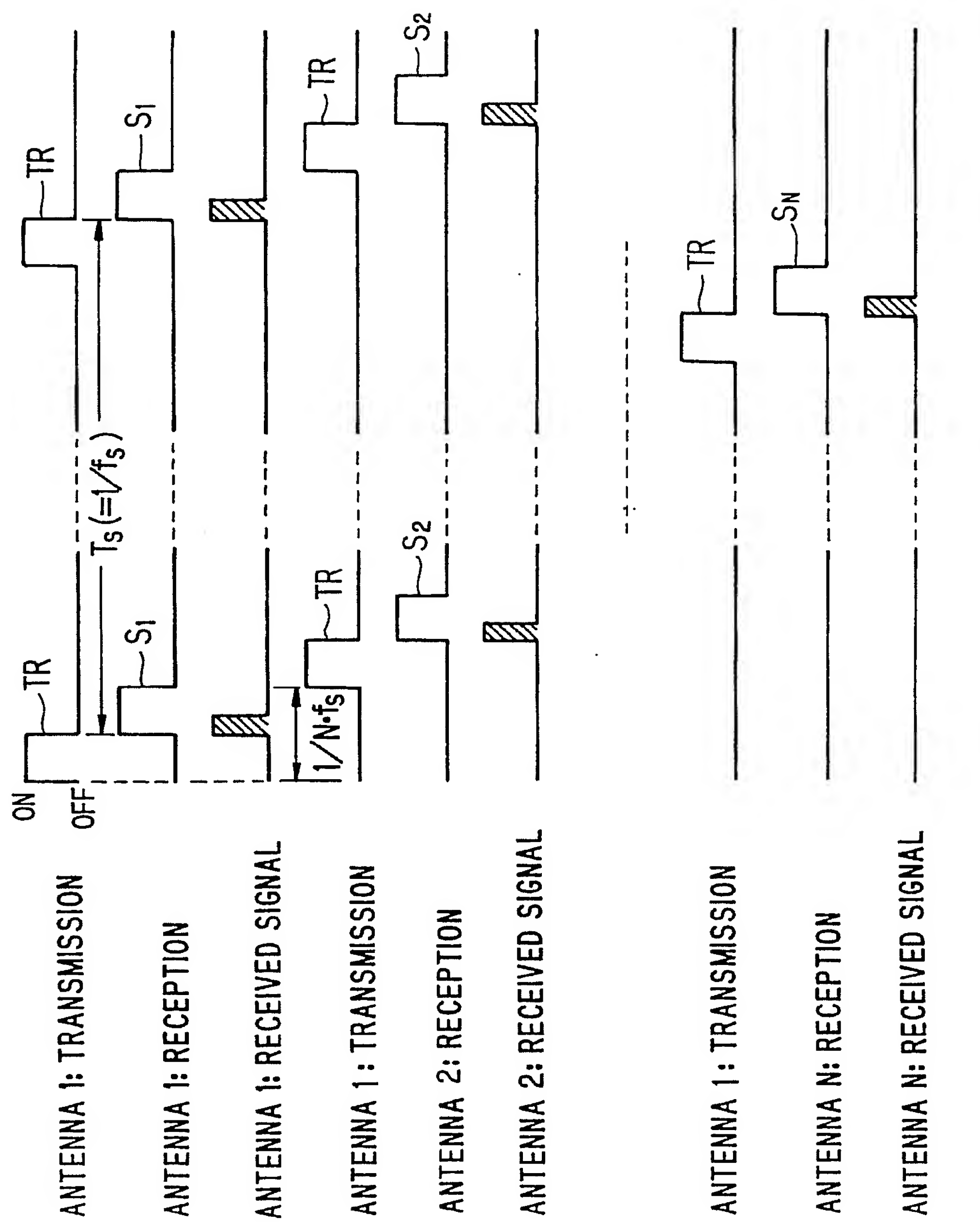

ANTENNA 1: TRANSMISSION
ANTENNA 1: RECEPTION
ANTENNA 1: RECEIVED SIGNAL
ANTENNA 1 : TRANSMISSION
ANTENNA 2: RECEPTION
ANTENNA 2: RECEIVED SIGNAL
ANTENNA 1 : TRANSMISSION
ANTENNA N: RECEPTION
ANTENNA N: RECEIVED SIGNAL
ON
OFF
TR
S1
S2
SN
Ts(=1/fs)
1/N·fs

FIG.22

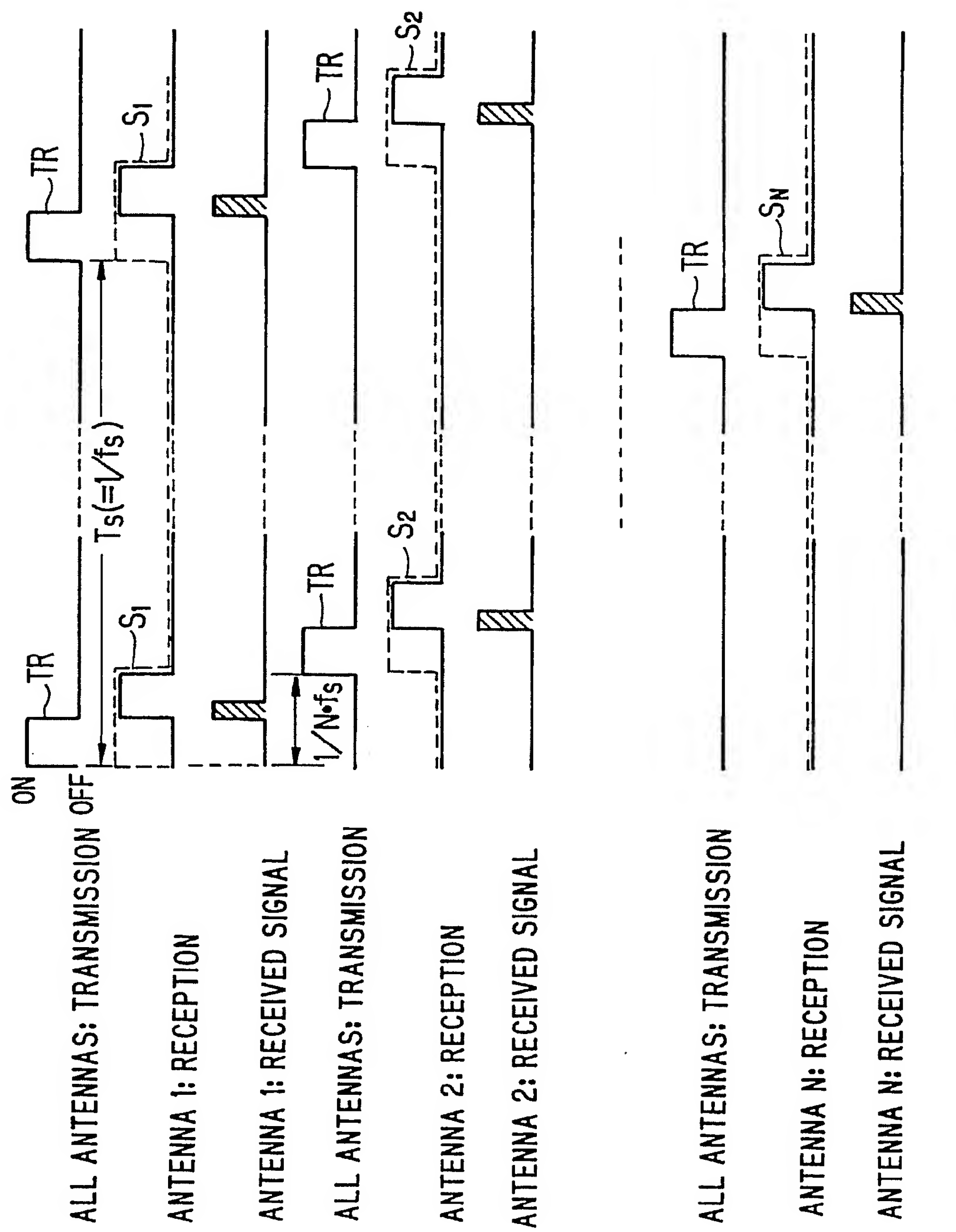

ALL ANTENNAS: TRANSMISSION
ANTENNA 1: RECEPTION
ANTENNA 1: RECEIVED SIGNAL
ALL ANTENNAS: TRANSMISSION
ANTENNA 2: RECEPTION
ANTENNA 2: RECEIVED SIGNAL
ALL ANTENNAS: TRANSMISSION
ANTENNA N: RECEPTION
ANTENNA N: RECEIVED SIGNAL
ON
OFF
TR
$T_S(=1/f_S)$
S_1
S_2
S_N
$1/N \cdot f_S$

FIG.24

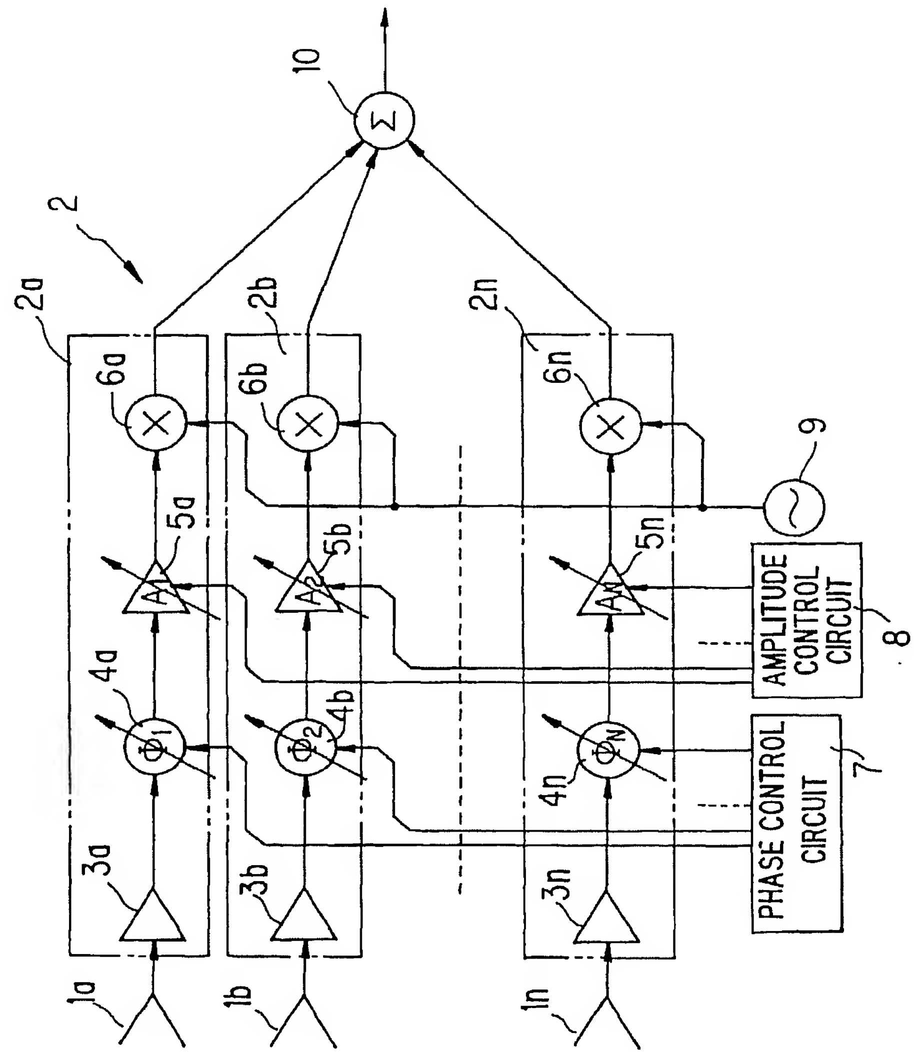
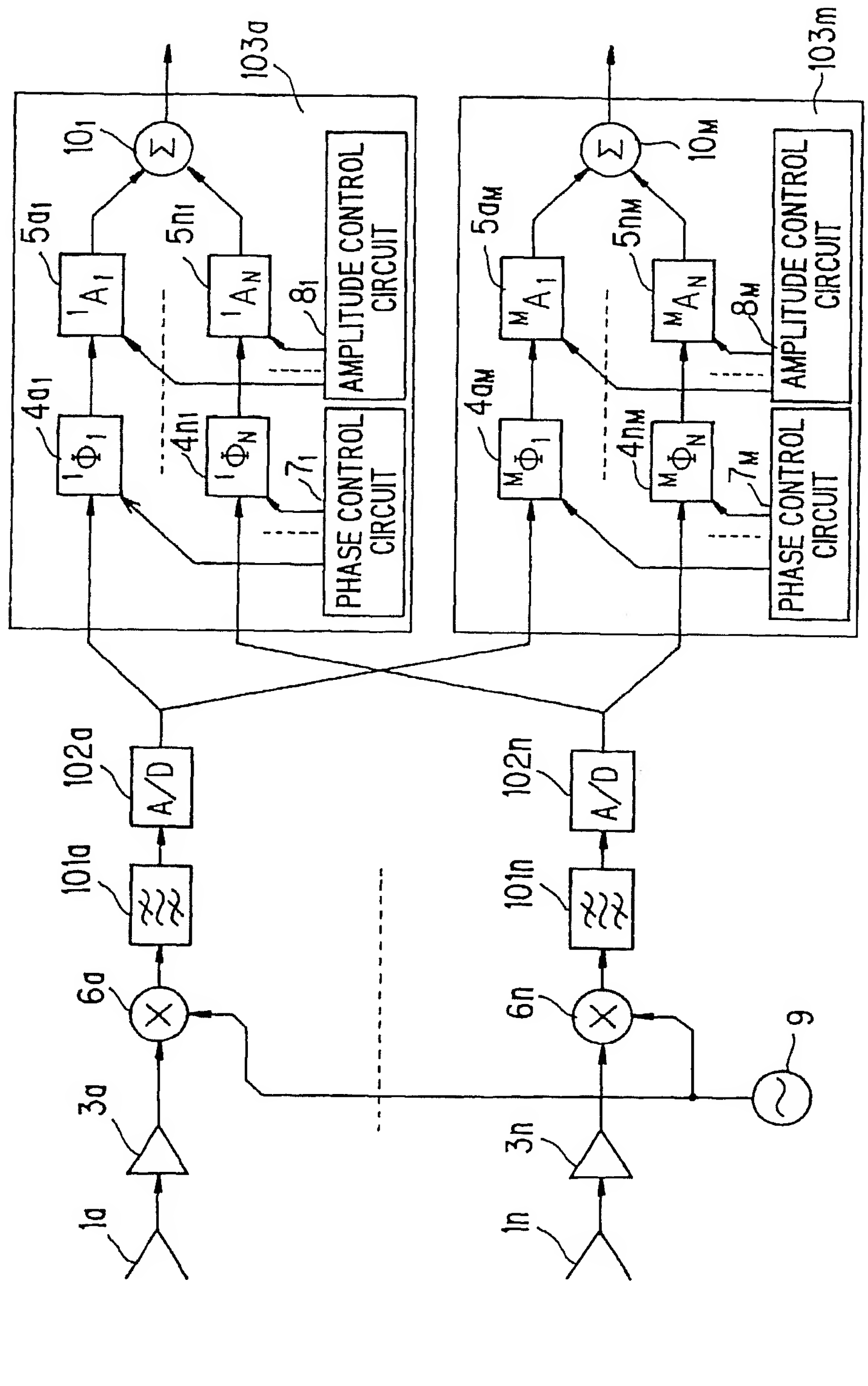

2
2a
2b
2n
1a
1b
1n
3a
3b
3n
4a
4b
4n
5a
5b
5n
6a
6b
6n
10
9
8
7
AMPLITUDE CONTROL CIRCUIT
PHASE CONTROL CIRCUIT

FIG.26


1a
3a
6a
101a
102a
A/D
1n
3n
6n
101n
102n
A/D
9
103a
10_1
$5a_1$
$5n_1$
$4a_1$
$4n_1$
$^1A_1$
^1A_N
$^1\Phi_1$
$^1\Phi_N$
7_1
8_1
PHASE CONTROL CIRCUIT
AMPLITUDE CONTROL CIRCUIT
103m
10_M
$5a_M$
$5n_M$
$4a_M$
$4n_M$
$^MA_1$
^MA_N
$^M\Phi_1$
$^M\Phi_N$
7_M
8_M
PHASE CONTROL CIRCUIT
AMPLITUDE CONTROL CIRCUIT

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 10 3806

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US 4 924 235 A (FUJISAKA TAKAHIKO ET AL) 8 May 1990 * figure 5 * ---	1-12	G01S7/285 H01Q3/24 H01Q3/26 G01S13/44
A	US 4 017 860 A (EARP CHARLES W) 12 April 1977 * figure 4 * * column 7, line 29 - line 30 * * claim 9 * ---	1-12	
A	EP 0 707 220 A (HONDA MOTOR CO LTD) 17 April 1996 * figure 3 * ---	1-12	
A	US 5 657 026 A (CULPEPPER JERRY W ET AL) 12 August 1997 * figure 4 * * column 3, line 54 - line 65 * * column 4, line 45 - line 53 * -----	1-12	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H01Q G01S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	16 November 1998	Ó Donnabháin, C

CATEGORY OF CITED DOCUMENTS

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